THE

Pneumatic Transmission

OF

MESSAGES AND PARCELS

BETWEEN

PARIS & LONDON,

Viâ

CALAIS AND DOVER.

PRELIMINARY STUDY AND SURVEYS.

BY

J. B. BERLIER,

CIVIL ENGINEER.

London:

E. & F. N. SPON, 125, STRAND. NEW YORK: 35, MURRAY STREET.

1885.

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GENERAL STATEMENT.

The persistence with which the Sub-Marine Tunnel scheme has been advocated in France and England, the great popularity acquired by this grand project among the masses on both sides of the channel, demonstrates how strong is the desire to improve and simplify the means of communication between the two countries. Unfortunately political or rather military susceptibilities stood in the way, and have so far succeeded in preventing the realization of this commercial necessity. Under these circumstances, there is every reason to fear that many years must elapse before a Sub-Marine Railway will provide rapid and comfortable means of transit for passengers and merchandise between Paris and London.

Nevertheless, the relations established between the two countries are becoming daily more intimate and more complicated, and it therefore becomes more and more urgent to establish quicker means of exchange, at least, for telegrams, letters, samples, printed matter, &c. Yet the present combined railway and steamer service can scarcely comport any further improvement. It has attained as reasonable a degree of perfection as can well be anticipated, though this is often insufficient to meet the exigencies of the modern commercial world, and the telegraph and the telephone have to supplement what railway and steamers cannot accomplish. But, if the electric wire conveys a message with the utmost speed, it is, nevertheless, an incomplete means of communication. More than a message is often required ; a sample, a document is frequently as urgently needed, and, finally, there is also the question on cost, which must be comparatively high when the telegraph is employed.

If a letter, or small parcel, could be sent from Paris to London, and *vice versâ*, with the same rapidity and security as a telegram, the very greatest services would be rendered to the community at large.

Politically, and socially, this would tend to increase the links of common interest and common friendship between the two greatest naval powers of Europe. Nor could any political or military objections be raised to such a plan. On the contrary, there is every reason to believe that the Governments, both of England and France, would view with favour an enterprise of this nature, and even assist in its realisation.

To achieve this end, it is proposed to lay two pneumatic tubes, an up and down line, between Paris and London, which would serve for the transmission of letters, telegrams, and parcels, weighing not more than 5 *kilogrammes, or* 11*lbs.*

The success obtained by this mode of forwarding telegrams and little parcels in Paris, and many other great European towns, is a powerful argument in favour of the above proposition. Of course the length of the tubes would be much greater, and the passage under the sea would be a complicated and gigantic application of the syphon now in actual use. Still, these difficulties are not insurmountable ; they are not even of a very serious nature. A careful study of the subject has led us to the conclusion, firstly, that the scheme is practical ; and, secondly, that the obstacles to be overcome, whether of a technical or financial character, are not of a formidable description.

These facts we may hope to establish by the following calculations :—

GENERAL SURVEY OF THE LINE.

Referring to the accompanying map it may be stated that the length of the Tube would be—

From Paris to Calais (land),	297	kilometres, or	184·50	miles.
,, Calais to Dover (water),	39	,,	24·20	,,
,, Dover to London (land),	139	,,	86·30	,,
Total	475	,,	295·00	

or say in round figures 500,000 metres.

As it will be necessary to follow the railway lines, the difference in the level on land are unimportant.

The most elevated point of the Northern Railway between Paris and Calais is at Gannes, the altitude being $121^{m}, 32$, or 398 feet, and the greatest depth of the sea is $56^{m}, 70$, or 186 feet, that is a total difference of

$$121^{m}, 32 + 56^{m}, 70 = 178^{m}, 02 \text{ ; or } 398 + 186 = 584 \text{ feet.}$$

The laying down of the tubes does not involve any technical uncertainty. Gas and water works where the pipes extend for thousands of miles have long ago settled this point.

As to the maritime section of 24·20 miles, numerous soundings have proved that the depth does not exceed 200 feet; that the bottom of the sea slopes gradually and gently, and the line designed to scale is so nearly level that the proportion of the length to the depth does not attain $1/600^{th}$.

Consequently the immersing of the tubes does not present much greater difficulty than the laying of an ordinary cable, particularly if we employ the various special means already experimented upon.

In a word, the laying down of the line of tubes, far from being impossible, presents no dfficulty whatever, when the enormous industrial resources of the present period are taken into consideration.

THE MODE OF TRANSMISSION.

Let us examine now what pressure of air will be required to send a train through the tubes.

Throughout the present memorandum, the forwarding tube is treated like a cylinder of great dimensions, in which the train represents a piston acted upon by compressed air without expansion.

Consequently we have here a maximum of expenditure, the eventual expansion producing a saving at the same time as it cools the train and the heated tube.

For argument sake, we will take one hour, or 3,600 seconds, as the time required for the journey of a train from Paris to London, with departures at intervals of ten minutes.

The weight of a train is not to surpass 10 kilos., or 22 lbs., and is to carry 11 lbs., or 5 kilos., of telegrams and parcels.

Let us now examine the various elements of the scheme on this basis :—

Quantity of Air required for the Transmission of a Train.

The length of the tube is $310\frac{1}{2}$ miles, or 500 kilometres; the diameter 11·8 inches, or 300 $^{m}/_{m}$; the volume,

$$V = \pm R^2 H$$

will be

$$V = 3{,}14 \quad 0{,}0225 \times 500000$$
$$= 3{,}14 \times 225 \times 50$$
$$= 35325^{m3}\ (1{,}247{,}600 \text{ cubic feet}) \text{ of air.}$$

Speed of Trains.

The speed of the trains per second will be :

$$V = \frac{500000^{m}}{3600''} = 138^{m},\ 90\ (456 \text{ feet}),$$

or say 139 metres per second; and if we reduce the expansion of air to a unit per second this expansion will be :

$$\frac{35325^{m3}}{3600''} = 9^{m3},\ 810 \text{ per second, or } 346 \text{ cubic feet per second.}$$

To sum up, in order to give to a column of air of 30 centimetres, or 11.8 inches, of diameter a speed of 500 kilometres, or $310\frac{1}{2}$ miles an hour, and consequently a similar speed to the train pushed by it, a volume of air of 9^{m3}, 810, or 346 cubic feet, per second is required.

Pressure of the Air.

We will now inquire what must be the pressure of this column of air so as to overcome passive resistance and loss of power. What are these obstacles ?

1. The work of elevating the train from the level.
2. The friction of the train on the sides of the tube.
3. The friction of the air itself in the tubes.

1. In our estimate of the work of elevation, corresponding to the difference in the level, we do not take into account the saving resulting from the falling gradients, which we treat as level, in order to keep on the safe side.

We find the sum of the gradients to be represented by the following:

From Calais to Paris	313^{m}	in 124 kilos.	or 1027 feet	in 77 miles.
Do. do. to Dover	$56^{m}70$	in 15 ,,	or 186 ,,	in $9\frac{1}{3}$,,
Do. Dover to London	313^{m}	in 124 ,,	or 1027 ,,	in 77 ,,
Total	682^{m}	in 263 ,,	or 2240 ,,	in $163\frac{1}{3}$,,

(We take the same figures for the gradients of the English railways as for the French, and are thus certainly on the safe side).

We shall have to raise a weight of 10 kilograms, or 22 lbs., to a height of 682 metres, or 2,237 feet, in 1,892 seconds, representing an expenditure of energy equal to

$$\frac{682 \times 10}{1892} = \frac{6820}{1892} = 3^{kgm}\ 6, \text{ or 26 foot pounds per second.}$$

The power absorbed under this head need not be taken into consideration.

2. We may compare the friction of the train in the tube to a mass of the same weight to be displaced on a flat surface, say the co-efficient 0·70.

This co-efficient, which is very high, is that of the leather trimming on the cast iron piston, and certainly higher than the asbestos trimming which will be applied to our trains; further, this is lowered to about one-half by the motion, but we consider it right to retain it owing to any unevenness which might be encountered in any part of the tubes.

The total weight being 10 kilos., or 22 lbs., the friction will be:

$$F = {}_{\iota}P = 0{,}70 \times 10 = 7 \text{ kilogrammes, or } 15\tfrac{1}{2} \text{ lbs.}$$

The friction taking place for one hour and during journey of

500,000 metres, the power required to overcome it is expressed in kilogrammetres:

$$F = \frac{500000 \times 7}{3600} = \frac{35000}{36} = 972 \text{ kilos, or } 7014 \text{ foot lbs. per second,}$$

or say in round figures about 14 HP.

3. As regards the friction of the air itself on the sides of the tube, no trials on a sufficiently large scale have been made, which might serve as a correct basis for calculations. A trifling error in this respect would of course be unimportant in a short distance, but in a long distance, this might become very serious.

It may, however, be asserted that this friction will not absorb more power than the displacement of the train itself; the figures obtained in that case were 14 HP., but they may safely be considered as excessive.

To prove this, we here reproduce an extract from the lectures by Callon, at the Mining School of Paris, which throws a favourable light on the question.

We read on page 302, vol. 1:

"The charge of seven atmospheres produced by compression, "transmitted itself to the perforated machines without any appreciable "loss by the friction. This result might have been foreseen, although "it astonished many Engineers.

"This result also explains why the difficulties of ventilation in "this great undertaking, anticipated by many engineers, were not "encountered." And further on: "It may be deduced from the pre- "viously stated result, proved on a large scale by the Mount Cenis "Works, that if tubes of sufficient size are employed compressed air "is a very desirable means of transmitting a given motive power to "long distances, with only trifling waste."

The importance of this quotation, taken from the writings of a great authority, is beyond discussion.

But to return to our first point. Our studies, as above, satisfy us that the friction caused by the train in the tubes, and of the air in the tubes, is expressed by the figures 28 to 30 HP., and that they are more than sufficient.

Let us now ascertain what pressure would be required for the proposed work, taking the diameter of the tube as $300^{m}/_{m}$, or 11·8 inches, and the distance to be traversed in one hour as 500,000 metres, 310·5 miles.

Calculation of the Initial Power wanted for the Compressed Air.

The diameter of the pneumatic tube being $300^{m}/_{m}$ or 11·8 inches, the section is

$$\surd\ R^2 = 706^{cmq} = 109{\cdot}4 \text{ square inches,}$$

the distance per second, as we know, is

$$\frac{500000}{3600} = 138^{m},\ 9, \text{ or } 139 \text{ metres, or } 456 \text{ feet,}$$

the producing power is 30 HP., say in kilogrammetres,

$$30 \times 75 = 2250 \text{ kilogrammetres.}$$

By the application of the known formula we get

$$T = \frac{706 \times P\ 1 \times 39,}{1''}$$

that is to say

$$2250 = 706 \times P \times 139\ ;$$

which results in

$$P = \frac{2250}{706 \times 139} = \frac{2250}{98134} = 0^{k},0229.$$

We have not introduced into the theoretic formula the practical co-efficient 0·50 ; the result should therefore be multiplied by 2 and the pressure required is

$$0{,}0229 \times 2 = 0^{k},0458 = \tfrac{2}{3}\text{lb. per square inch.}$$

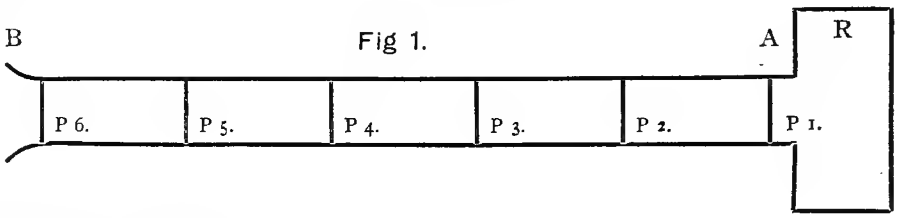
It results from the above calculations that by supplying per second $9^{m3},810$ air by a pressure of $0^{k},0458$, a train weighing 22lbs. and presenting a surface of 706^{cmq}, or 109·4 square inches, could be sent in one hour from Paris to London.

It is certain that if compressed air in the reservoirs is produced at a pressure of 4 kilogrammes we shall be able to provide against any eventuality, even the most unfavourable one, because we should dispose of a power 40 times in excess of the one indicated in the calculation.

Speed of the Trains.

Let us now see what takes place in the tubes while the trains travel, and let us take the following figure, viz.:

Fig 1.



A B is the conduit.

R a reservoir for compressed air, where the pressure is continuously maintained.

P 1, P 2, P 3......... the trains forming the piston.

If we suppose a departure every ten minutes, we shall have six trains in the tube at the same time, separated by an interval of

$$\frac{500000}{6} = 83{,}000 \text{ metres or } 52 \text{ miles,}$$

and this interval would be maintained (in the hypothesis that both the tube and the trains are absolutely air-tight, and without paying attention to loss of power by friction), by a charge of imprisoned air between each piston, which for the entire length of the distance from the 83rd kilometre, or 52nd mile, would serve no other purpose than that of a simple tie.

This is corroborated by the following, which we extract from the "TELEGRAPH ANNUAL," 1875, page 448:

" By carelessness, the clerk had given the signal for the reception
" long before the arrival of the train. When the train following that
" one arrived, he pushed the first one and put the second one in its
" place; on arrival, the one was taken for the other, and so on for
" part of the day, until the mistake was discovered by checking the
" way-bills.

In reality, and according to the above hypothesis, compressed air does not act as a motive power beyond 52 miles, say one-sixth part of the distance to be traversed, for it may be assumed that the remaining force will be absorbed by the waste caused by friction. In any case, should any power remain, it will be entirely in favour of our calculation.

The number of trains circulating, also renders it necessary to augment the initial pressure in the same proportion.

Thus for example, in the case of six trains an hour:

$$0{,}0459 \times 6 = 0^{k},\ 2754, \text{ or } 4 \text{ lbs. per square inch,}$$

and if a maximum of 20 journeys could be obtained we should require

$$0{,}0459 \times 20 = 0^{k},\ 9180, \text{ or } 13 \text{ lbs. per square inch,}$$

and this would still be inferior to 2 kilos. (4 lbs.), previously mentioned.

Obstructions.

Although the normal pressure is inferior to one kilogramme, our tubes and certain reservoirs will be constructed to resist 15 kilos. (214 lbs. per square inch), and a special compressor would be installed for this purpose, in view of any obstructions which might take place in an inaccessible part of the tubes. In such a case we should dispose of a force of (the given diameter of the tube being $706^{\text{cmq.}}$)

$$706 \times 15 = 10590 \text{ kilogrammes} = 23340 \text{ lbs., or } 10\tfrac{1}{2} \text{ tons,}$$

and it cannot be admitted that any strange body introduced into the tube could resist such pressure.

By aid of M. Bontemp's method, called the "Pistol Shot," the position of any obstructing body may be ascertained within about two or three yards, and as to the means of freeing the pipes from such foreign bodies they have been tried practically on pneumatic lines now in use, and this so very often as to leave no doubt of their efficacy. (*See the* "TELEGRAPH ANNUAL" of 1875, page 445 to 450.)

Works on the Road.

If the hypothesis as to the air-tight character of the tube is absolutely realised, it is evident that works at each end of the line would be sufficient. But this is not probable—escapes will take place, which, in addition to the loss of power caused by the friction of the air in the tube, tend to diminish progressively the length of the tie piece, and consequently the speed of the trains.

To constantly maintain this speed we have foreseen the desirability of adding supplementary works on the road, which could supply the same pressure as at the initial works, and would rigorously maintain the trains in their relative positions during the entire length of the journey.

Let us add that electric indicators combining the various works or stations would enable the engineer in charge of the supplementary works to regulate the pressure according to the force used at the starting point.

It has been shown above that the actual transmission of messages could be easily brought about, while the laying down of the pipes offers no insurmountable difficulty.

As this paper is written solely to prove the original idea, we do not enter here into details as to the construction of the trains and the means of putting them on the road.

Let us simply say that the trains would be of great lightness, combined with the greatest possible strength, and be made of a steel wire skeleton covered by asbestos and metal wires, forming a brush, and making a water and air-tight joint.

Stations on the Road.

On the most important points of the line, supplementary trains might be added without any difficulty resulting therefrom likely to impede the chief service to Paris from London.

COST OF CONSTRUCTION. GENERAL EXPENSES AND SINKING FUND. YEARLY PROFITS.

The first cost of construction would be:

1. The tubes.
2. The works.

Tubes.

The land sections of the tubes would be of

$184\frac{1}{2}$ miles,	or 297	kilometres	from	Paris to Calais,
86 ,,	or 139	,,	,,	Dover to London.
$270\frac{1}{2}$,,	or 436	,,		and the maritime section would

be 24 miles, or 39 kilometres in length.

Trenches.

As previously stated the tubes would be laid down in the trenches following the lines of the French and English Railways. These trenches, to be big enough for the double tubes (going and coming), should have the following dimensions:

Breadth, 1^m 20, 4 feet.
Depth, 1^m, 3 feet 3 inches,

which in round figures, would present earthworks on a length of 450 kilometres, or

$$450000 \times 1 \times 1,20 = 540000^{m^3}, \text{ or } 706000 \text{ cubic yards.}$$

Cast Iron.

The double tubes represent on land:

$$450000 \times 2 = 900000 \text{ metres, or } 558 \text{ miles}$$

in pipes of 300 $^m/_m$ diameter, or 11·8 inches.

The weight of the pipes being 220·46 lbs. or 100 kilogrammes per metre, the total weight of the cast iron would amount to for those sections,

$$900000 \times 100 = 90,000,000 \text{ kilogs.},$$

say 90000 tons.

The length of the maritime section (going and coming) would be in round figures 80 kilometres, the weight therefore is:

$$80000 \times 100 = 8,000,000 \text{ kilos.},$$

say 8000 tons.

The whole of the land and sea sections represent a total weight of 90000 × 8000 = 98000 tons, say in round figures 100000 tons.

Laying down and Joints.

The cost of laying down will be according to the number of joints. As we use pipes of 13 feet, or 4 metres, in length we shall have, for the land sections,

$$\frac{900000^{m}}{4} = 225000 \text{ joints.}$$

Cost of the Tubes, and their putting Into position.

1. Land section, 540000^{m3} of trenches, at 1 fr. the cubic metre	£21,600
2. 90000 tons of Cast Iron, at 160 frs. per ton, delivered free...	576,000
3. Laying down, at 15 frs. per joint (much exaggerated)	135,000
4. Marine section, 10000 tons at 160 frs. per ton ...	64,000
5. Putting down, at 200 frs. per metre (much exaggerated)	320,000
Total	£1,116,600

Works.

We said we should require per second 9^{m3}, 810 compressed air at 0^{k}, 275 to send six trains per hour or 0^{k}, 0458 for a single train.

We shall establish the motive power per hour required for a single train, which power must afterwards be multiplied by the number of departures per hour.

The necessary work to compress air is expressed by the formula:

$$T = \surd\ P,$$

$\surd$ being the quantity per second in cubic metres, and P the pressure on a surface of one square metre.

We have therefore

$$T = 9^{m3},810 \times 0^{k},0458 \times 10000^{cmq}$$
$$= 9810 \times 458$$
$$= 4492 \text{ kilogrammetres,}$$

say in horsepower:

$$\frac{4492}{75} = 60 \text{ HP in round figures.}$$

These figures are obtained without taking into consideration the difference of the power due to elevation of the temperature by pressure. This, however, being very slight, there will be but little difference in the figures.

In proof of this, we refer to Table XIV., page 85, of the work "Compressed Air," by Pernolet, and we shall see that to raise to 1^{atm}, 300 say 0^{k}, 300, 1^{kg} saturated air, we must expend 2537 kilogrammetres.

On the other hand this pressure 0^{k}, 300 corresponds about to

$$0{,}0458 \times 7 = 0^{k},3206$$

required for the sending of seven trains an hour.

If we establish our calculations on this basis, we shall find that we shall have to compress 9^{m3}, 810 × 1^{k}, 3 (density of the air) = 12^{kg}, 75 by a pressure of 0^{k}, 300; we take for this 2537 × 12,75 = 32346 kilogrammetres, say for a single train

$$\frac{32346}{7} = 4620 \text{ kilogrammetres}$$

figures very similar to those we arrived at when we took no heed of the elevation of temperature.

To sum up, we must have at our command 60 HP per train-hour, when working.

If we fix the maximum at 20 trains, the total power of the machine should be:

$$60 \times 20 = 1200 \text{ HP.}$$

The cost price of the principal works may be estimated as follows:—

Machines of 1,200 HP at 500 fcs. each	£24,000
Boilers of 1,500 HP at 100 fcs. each...	6,000
Machines for pressing	24,000
Reservoirs for compressed air...	6,000
Tools for dispatch and reception of trains	8,000
Buildings and various	4,000
	£72,000

or for the two chief workshops £144,000

The installation of 7 supplementary stations and works on the line may be estimated at £40,000.

TOTAL COST OF WORKS

The original cost of works may be put down as follows:—

The laying down and cost of tubes	£1,116,600
Train workshops	144,000
Supplementary workshops	40,000
Unforeseen expenses	59,100
Total	£1,360,000

Cost of Working. Expenditure of Coals.

In case of 6 journeys per hour each day, say in all 12 journeys, the expenditure of coals would be:

$$12 \times 60 \text{ HP} = 720 \text{ HP per hour}$$

say per day:

$$20 \times 24 = 17280 \text{ HP},$$

and for the working year of 300 days:

$$17280 \times 300 = 5184000 \text{ HP}$$

For engines of this power the expenditure of coal does not exceed 1^k, 2 (2.6 lbs.) per HP per hour.

The total expenditure therefore is:

$$5184000 \times 1{,}2 = 6220 \text{ tons:}$$

at £1 4s. per ton:

$$6220 \times 1'4 = £7{,}464$$

Interest and Amortissation of the Capital in 40 years.

The capital to be redeemed in 40 years is £1,360,000.

Amortissation, including interest, will absorb an annuity of 6 per cent. say:

$$\frac{1{,}360{,}000 \times 6}{100} = 2{,}040{,}000 \text{ fcs. or } £81{,}600.$$

Office Expenses.

500 men for distributing messages at 2000 fcs.	£40,000
Repairs to tubes and works	20,000
Ground-rent and taxes	40,000
Office and administration	20,000
Total	£120,000

The cost of working and amortissation forms the total of:

Coals	£7,464
Greasing and lighting	536
Interest and sinking fund	81,600
Staff, office, and repairs	120,000
Unforeseen expenses	10,400
Total	£220,000

Cost per Train.

With a minimum of six trains each way, say 12 trains per hour, we have,

Per day, 12 × 24 = 288 trains, and
Per year, 288 × 300 = 86400 trains.

The cost of working will be £220,000, consequently,

$$\frac{£220,000}{86400} = £2\ 6s.\ 11\tfrac{1}{2}d.$$

RECEIPTS.

We stated that a train carries 5 kilogrammes of telegrams, say at a tarif of 25 centimes, per 15 grammes a train would earn,

$$\frac{0,25 \times 5000 \text{ gr.}}{15} = 83 \text{ fcs., or } £3\ 6s.\ 5d.,$$

and as at least 86,400 trains per annum would be sent the profits would be,

86,400 × 83, = 7,171,200 fcs. or £286,848.

The profit on each train would be,

83—63·65 = 19 fcs. 35, or 15s. 6d.,

and by year,

£248,848—£220,000 = £66,848,

representing, in addition to the interest, a dividend of 4.90 per cent.

But it must be observed that these figures are based on the amortissation in 40 years, of a capital of £1,360,000, which is certainly a somewhat high figure, and that on the other hand we have calculated on only 12 trains per hour, while 30 or 40 might be employed.

RECAPITULATION.

1. It is not only possible, but relatively easy to create means for the pneumatic transmission of telegrams between Paris and London, and the intermediate stations, the journey to be accomplished in one hour.

2. The Capital required to establish this pneumatic line does not exceed £1,360,000.

3. By sending 6 trains each way, 12 per hour, and by redeeming the capital in 40 years, a dividend of 4,90 per cent. per annum would be earned in addition to the interest.

4. These figures are based on 300 working days per year.

5. The realisation of the project will satisfy a public necessity, and will be highly beneficial if judged from an international, commercial, and industrial point of view, and therefore recommends itself especially to the good-will of the English and French Governments.

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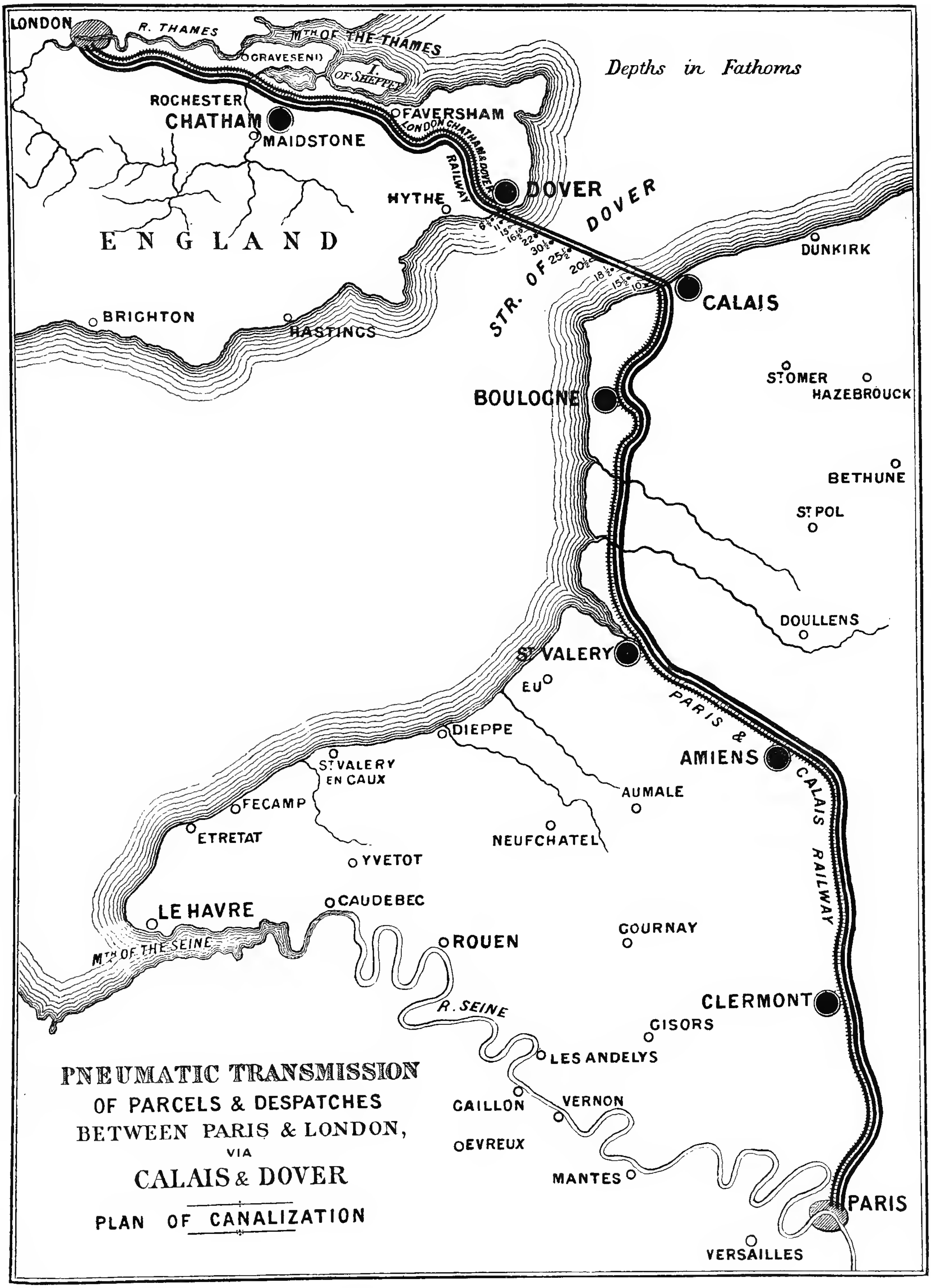

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